

CHARMED HADRONS PRODUCTION IN HIGH-ENERGY Σ^- BEAM

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Abstract

We present the calculation of the inclusive x_F -distributions of charmed hadrons, produced in high-energy Σ^- -beam. Our calculation is based on the modified mechanism of charmed quarks fragmentation as well as on the mechanism of c -quark recombination with the valence quarks from initial hadrons.

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Perturbative QCD provides a reasonable description of the experimental data on the inclusive cross sections of open charm and beauty production on fixed targets [1]. However, it is well known that the experiments indicate that there is a substantial difference in the production of the charmed and anticharmed hadrons in the fragmentation region of the initial hadrons (a leading particle effect). This leading particle asymmetry A is defined as follows:

$$A \equiv \frac{\sigma(\text{leading}) - \sigma(\text{nonleading})}{\sigma(\text{leading}) + \sigma(\text{nonleading})}. \quad (1)$$

It worth to note, that perturbative QCD calculation [1] is unable to reproduce this effect. Indeed, in the quark parton model framework the production of hadrons containing a heavy quark proceeds via two subsequent stages

- heavy quark pair $Q\bar{Q}$ is produced as a result of the hard collision of the partons from the initial hadrons (e.g. the subprocesses $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ in Born approximation);
- transition of the heavy quarks c into charmed hadrons (“hadronization”).

The standard way of describing heavy quark hadronization is to use the fragmentation function $D(z)$ of the heavy c -quark into the charmed hadron (D -meson or baryon) (here $z = |\vec{p}_D|/|\vec{p}_c|$ is the fraction of the heavy quark momentum carried away by the charmed hadron D).

It should be noted that the usage of the fragmentation function assumes the absence of the interaction of the produced heavy quark Q with the remnants of the initial hadrons. Therefore, it should be no difference between the spectra of charmed and anticharmed hadrons. Moreover, any modification of the fragmentation mechanism can not reproduce the production asymmetry (the leading particle effect).

Note, that the fragmentation mechanism can be apply for the production of the $c\bar{c}$ pair in the color-singlet state or for high p_T production of the open charm. On the other hand, for the case of the hadronic production of color $c\bar{c}$ pair with small p_T one should takes into account the possibility of charmed c and \bar{c} quarks interaction with the initial hadron remnants. Therefore, due to the different valence quarks in the initial hadrons one may expect the different inclusive spectra of the final charmed hadrons.

In the parton model framework, a heavy c -quark should interact with a high probability with its nearest neighbor in the rapidity space able to form a color-singlet state with it. In some cases, the heavy antiquark may find itself close (in rapidity space) to a valence light quark from the initial hadron. This would result in the formation of a fast heavy meson in the fragmentation region of the initial hadron. Alternatively, the proximity of a heavy quark to a valence diquark results in the fast charmed $B(cq_1q_2)$ -baryon production.

Therefore, the "hard" part of charmed hadron spectra is very sensitive to the form of valence quark distribution in the initial hadrons.

In this note we consider the charmed hadron production in high-energy beam of Σ^- -hyperon. We may expect the different behavior of the distributions of the valence d - and s -quarks. As a result we should observe the different x_F -dependence of spectra of charmed hadrons with d - or s -quarks, namely, $D^-(\bar{c}d)$ and $D_s^-(\bar{c}s)$, $\Xi_c^0(cds)$ and $\Sigma_c^-(cdd)$, etc.

Indeed, very roughly, the distribution of valence quark in the baryon $B(q_1q_2q_3)$ can be presented as follows [2, 3]:

$$V_{q_1}^B(x) \propto x^{-\alpha_1}(1-x)^{\gamma_b-\alpha_2-\alpha_3}, \quad (2)$$

where α_i is the intercept of the leading Regge-trajectory for q_i -quark, while $\gamma_B \simeq 4$. Note, that due to violation flavor $SU(N)$ -symmetry, we have different intercepts for $d(u)$ - and s -quarks [4, 5]:

$$\alpha_u = \alpha_d = \frac{1}{2}, \quad \alpha_s \approx 0, \quad \alpha_c \approx -2.2. \quad (3)$$

As a result, the x -dependence of the valence d and s -quark in the $\Sigma^-(sdd)$ -hyperon has the form as follows [2]:

$$V_d^\Sigma \sim \frac{1}{\sqrt{x}}(1-x)^{3.5}, \quad V_s^\Sigma \sim (1-x)^3 \quad (4)$$

It is seen from the (4) that the valence s -quark in the Σ^- -hyperon has slightly harder x -distribution than that for d -quark.

We use the model [2, 3] to describe the production asymmetry for charmed hadrons. In this model the interaction of the charmed quarks with valence quarks from the initial hadrons describes with the help of the recombination function [2, 3]. The detail description of this mechanism is given elsewhere [2,

3]. The recombination of q_V and \bar{c} quarks into D -meson is described by the function of $R_M(x_V, z; x)$:

$$R_M(x_q, z; x) = Z_M \xi_q^{(1-\alpha_q)} \xi_c^{(1-\alpha_c)} \delta(1 - \xi_q - \xi_c), \quad (5)$$

where $\xi_q = x_q/x$ and $\xi_c = z/x$, while x_q , z , and x are the fractions of the initial-hadron c.m. momentum that are carried away by the valence q -quark, charmed c -quark, and the meson $M_{\bar{c}q}$, respectively. The corresponding recombination of three quarks into baryon can be described by means of the similar recombination function:

$$R_B(x_1, x_2, z; x) = Z_M \xi_1^{(1-\alpha_1)} \xi_2^{(1-\alpha_2)} \xi_c^{(1-\alpha_c)} \delta(1 - \xi_1 - \xi_2 - \xi_c). \quad (6)$$

These functions take into account the momentum conservation and the proximity of partons in the rapidity space. Actually, the recombination function is the modulus squared of the heavy meson wave function in momentum space, being considered in the infinite momentum frame in the valence quark approximation.

As a result, the total differential cross section for the production of H_c -hadron looks as follows:

$$\frac{d\sigma(H_c)}{dx} = \frac{d\sigma^R(H_c)}{dx} + \frac{d\sigma^F(H_c)}{dx}, \quad (7)$$

where the first term in the r.h.s. is the cross section for H_c -hadron production due to the recombination of the charmed c -quark with valence quarks from initial hadron, while the second term is the cross section for H_c production due to charmed quark fragmentation.

Note, that this model provides more or less successful description of the charmed D -meson production in $\pi^- N$ -interactions (see Fig. 1, 2 and [3] for details).

We use LO formulas for the cross sections of quark-antiquark and gluon-gluon annihilation into charmed quark pair. We set $m_c = 1.25$ GeV, $\alpha_s = 0.3$ and find the following cross section value of $\Sigma^- p$ interaction at $P_{LAB} = 600$ GeV:

$$\sigma(\Sigma^- p \rightarrow c \bar{c} X) \simeq 8 \mu b \quad (8)$$

In our calculations we do not pretend to reproduce the absolute value of this cross section (see [1], for detail consideration of this problem). We

concentrate on the description of x_F -distribution of charmed mesons and baryons. The corresponding distributions (integrated over p_T) are presented in Fig.3–5. We may see from these figures, that the considered charmed quark interaction in the final state (recombination) leads, indeed, to noticeable differences in x_F -spectra. These differences can be explicitly seen in Fig.6, where we present the corresponding asymmetry A (see (1) for definition). The most non-trivial prediction of the proposed model is presented in two lower plots in Fig.6, where we present the ratio of the inclusive spectra of $D_s^{*-}(\bar{c}s)$ and $D^{*-}(\bar{c}d)$ mesons. It is evident from this figure the difference of x_F -spectra of the these two mesons, which is a result of different x -distributions of the valence d -and s -quarks in the initial Σ^- -beam (see (4)).

Conclusion

In the present note we wish to stress once more, that the source of the observed asymmetry in charmed hadron production is the interaction of produced charmed quarks with valence quarks from initial hadrons. Note, the model under consideration provides also the additional method to measure the valence quark distribution functions of K -meson and Σ -baryons.

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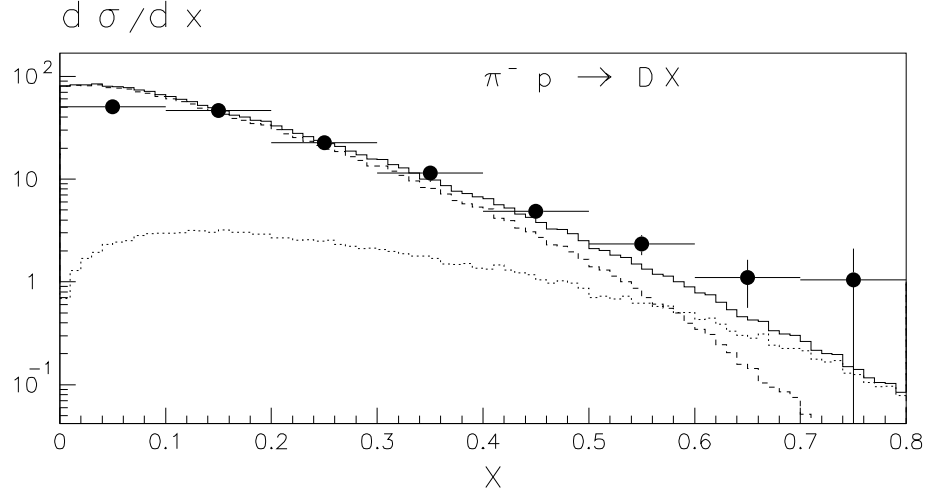


Figure 1: Differential distributions $\frac{d\sigma}{dx}$ for the energy of $E_\pi = 250$ GeV. The experimental data are taken from [6]. The dotted (dashed) histogram corresponds to the recombination (fragmentation) contribution. The solid histogram represents their sum. The cross sections are presented in μb (see [3] for details).

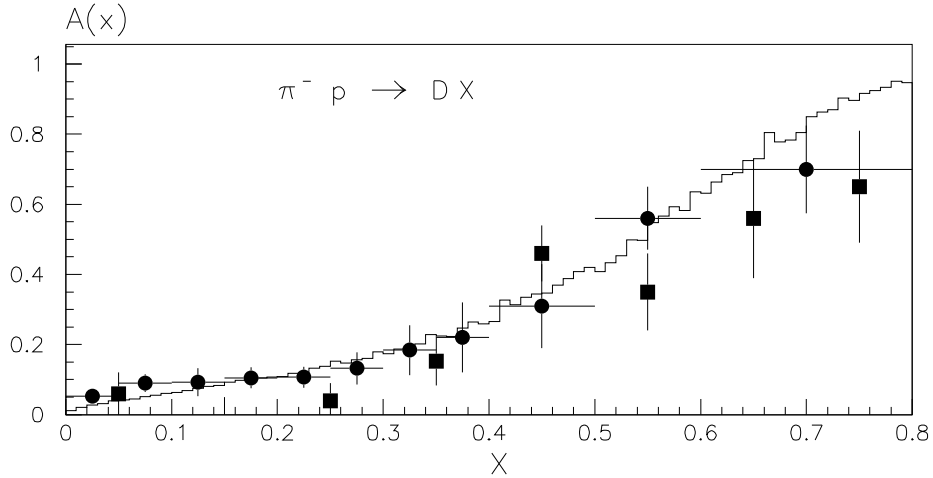


Figure 2: The description of the asymmetry $A(x)$ in $\pi^- p$ collisions [6, 7] (see [3] for details)

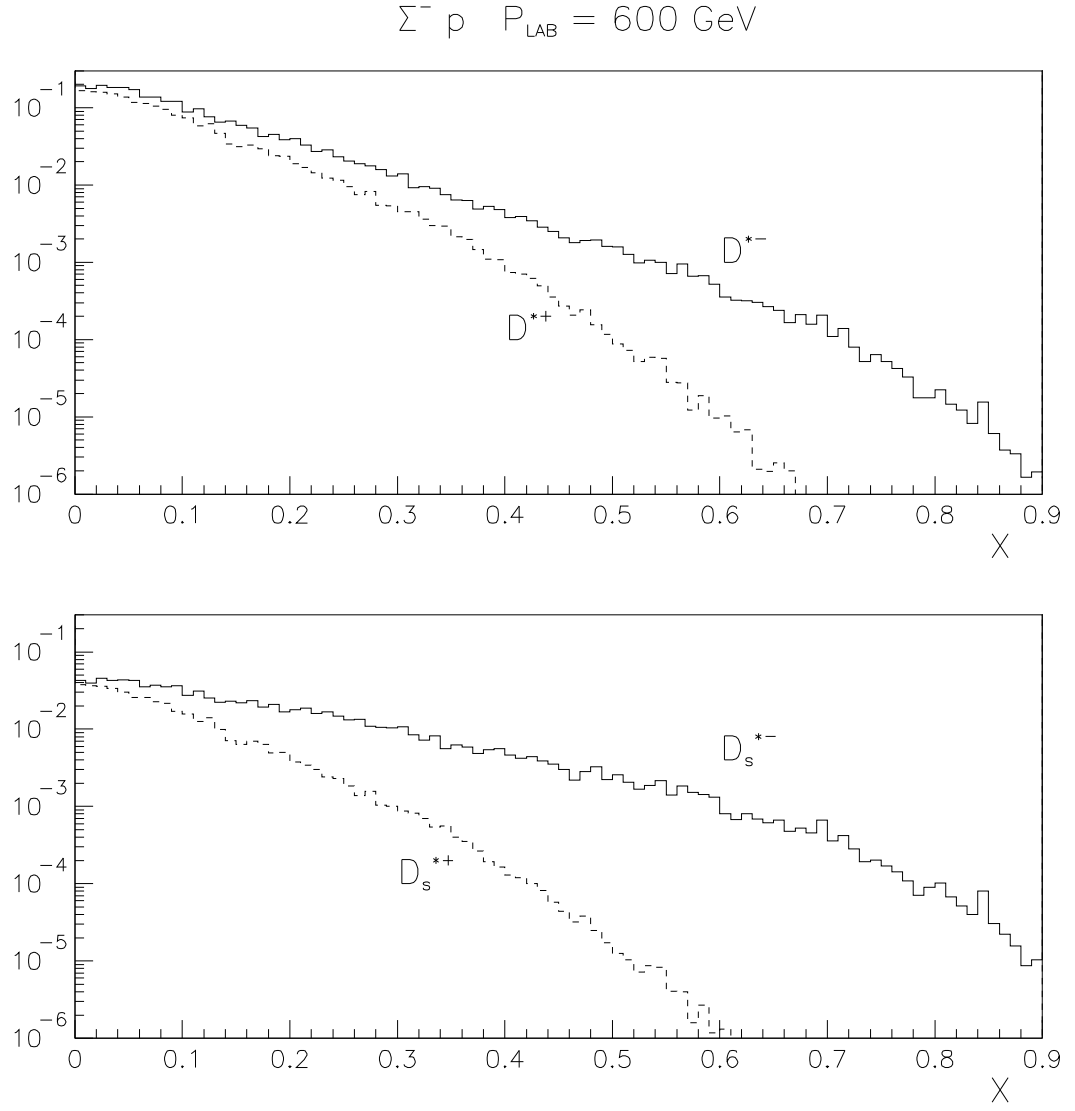


Figure 3: Differential distributions of $D^{*\pm}$ and $D_s^{*\pm}$ mesons produced in $\Sigma^- p$ interactions at $P_{\text{LAB}} = 600 \text{ GeV}$.

$\Sigma^- p \quad P_{LAB} = 600 \text{ GeV}$

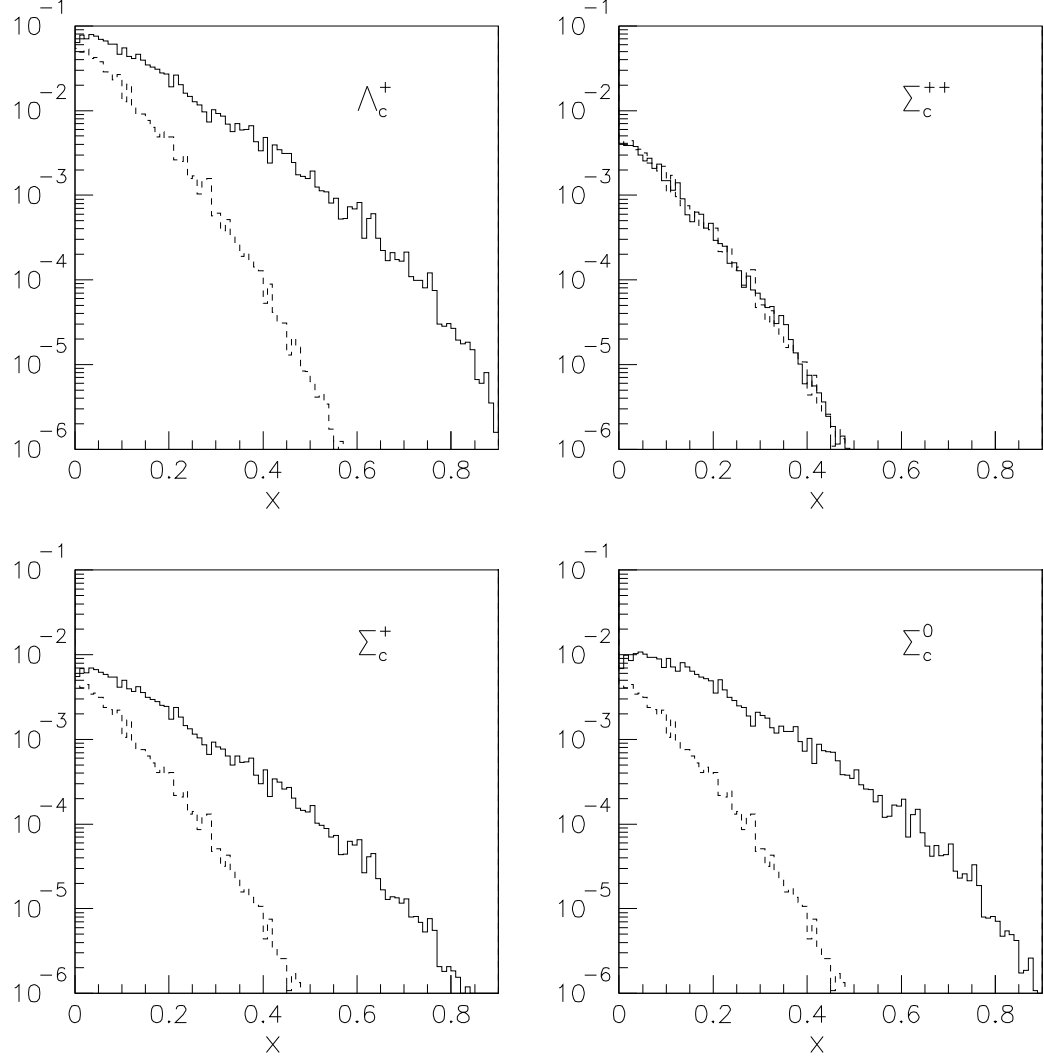


Figure 4: Differential distributions of charmed baryons, produced in $\Sigma^- p$ interactions at $P_{LAB} = 600 \text{ GeV}$. The solid (dashed) curves correspond to baryon (antibaryon) distributions.

$\Sigma^- p \quad P_{LAB} = 600 \text{ GeV}$

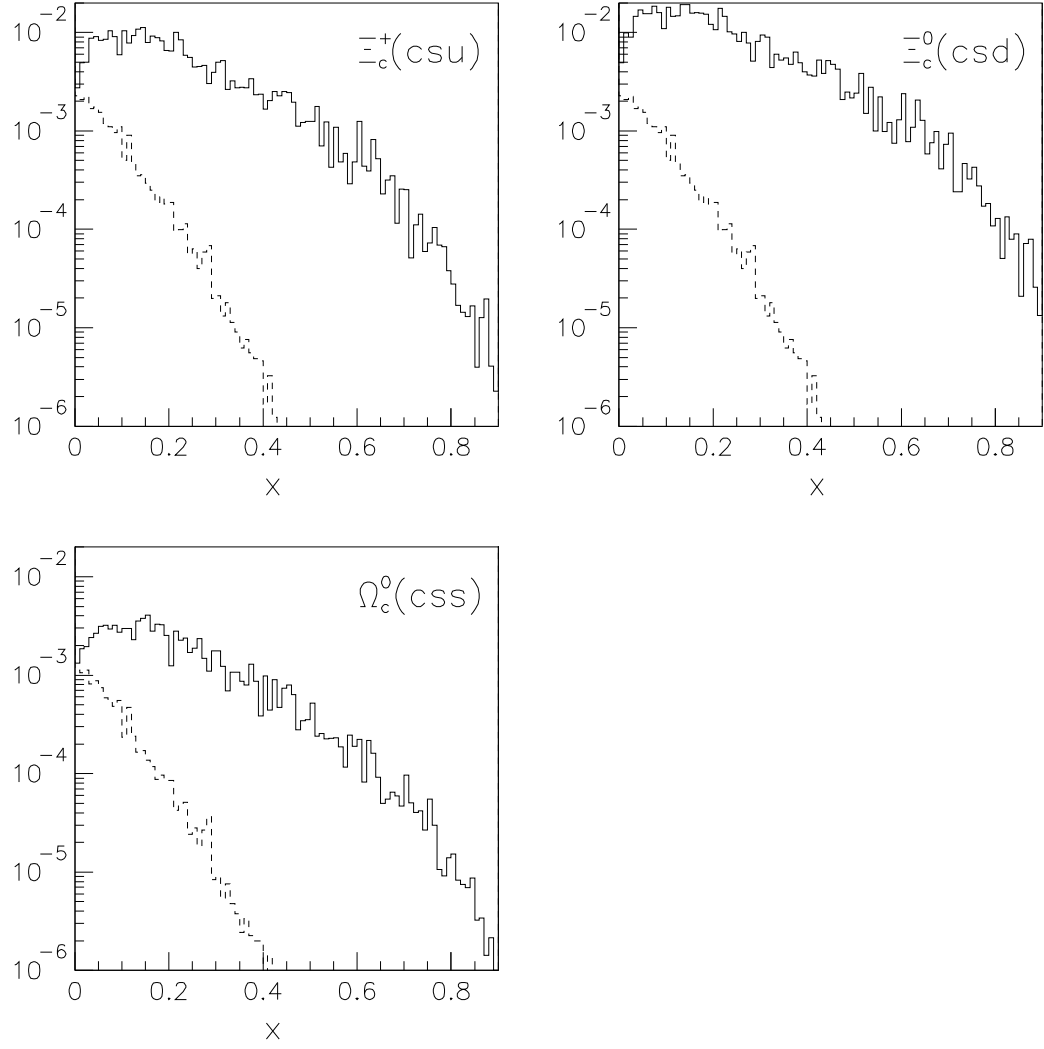


Figure 5: The differential distributions of charmed-strange baryons , produced in $\Sigma^- p$ interactions at $P_{LAB} = 600 \text{ GeV}$. The solid (dashed) curves correspond to baryon (antibaryon) distributions.

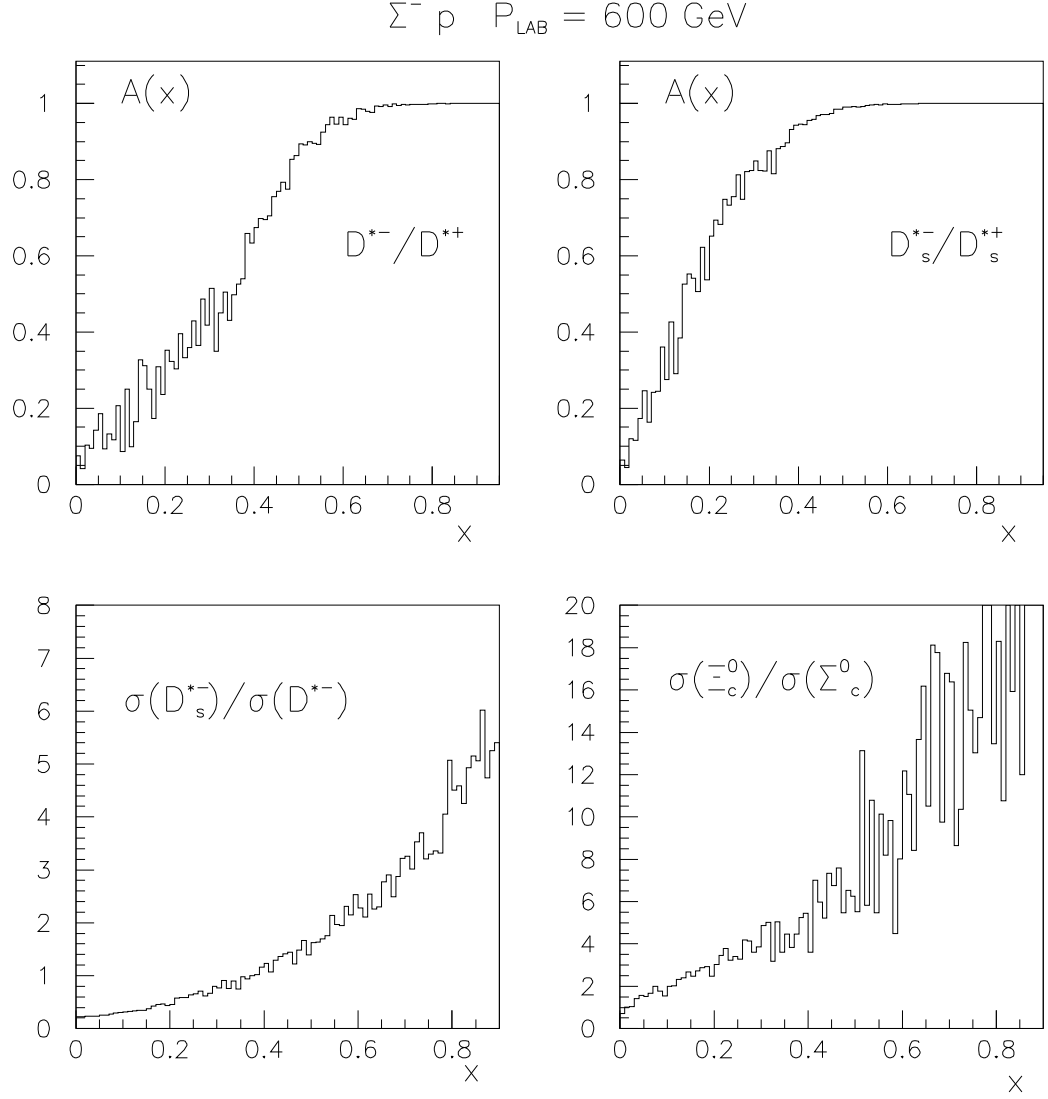


Figure 6: Production asymmetry for $D^{*\pm}$ and $D_s^{*\pm}$ mesons (two upper plots), produced in $\Sigma^- p$ interactions at $P_{LAB} = 600 \text{ GeV}$. Two lower plots present the ratio of the spectra of charmed hadrons with and without strange quarks (i.e. the D_s^{*-}/D^{*-} and $\Xi_c^0(cds)/\Sigma_c^0(cdd)$ ratios).